Optical Variability and Bottom Classification in Turbid Waters: Phase II

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LONG-TERM GOALS

Real-time determination of the optical and bathymetric climate available for operation of various naval assets in the coastal zone using a mixture of AUV and air/space-borne observational assets. Remote determination of inherent optical properties and bottom characteristics will be accomplished for input and validation data for predictive visibility and primary production models (e.g. see Walsh 1999) and for use in asset selection for naval operations.

OBJECTIVES

The development of optical methodologies valid for Case II coastal waters for the remote determination of water and bottom optical properties including visibility, bathymetry, bottom albedo, vegetation cover, and bottom structure are being pursued. These include interpretation of hyperspectral, high-resolution imagery from aircraft and satellites, development and deployment of suites of small instruments on remotely operated and autonomous underwater vehicles (ROVs, AUVs), and development/application of radiative transfer models and algorithms for predicting optical properties and extracting information from the remote data. Effects of vertical structure in the optical properties (e.g. river plumes, suspended sediments) and turbidity must be recognized for the data retrievals to be accurate, and instruments to quantify such structure will be developed and utilized on underwater vehicles and moorings.

APPROACH

We have developed models for inverting hyperspectral data from air- and space-borne sensors in vertically homogeneous waters and estimating absorption, back-scattering, and beam-attenuation coefficients, and bathymetry and bottom albedo (Lee et al. 1999). These can be used to predict where certain mine-counter-measure assets can productively be deployed or not given an adequate means of validating the model retrievals and simulating the performance requirements of the assets.

Water clarity, bathymetry, and bottom albedo are critical variables affecting optical searches for objects in the water column or on the bottom. Object contrast with the background optical field or its 3-dimensional shape can be used in object-classification schemes. We are using elastic and inelastic

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scattering and active and passive systems for use in object-classification schemes, and we are evaluating how system performance degrades with increased turbidity, range, and optical structure (e.g. layers) over a variety of bottom types.

We have developed several optical packages for deployment on ROVs and AUVs to measure the optical properties of the water column and bottom to provide an assessment of the accuracy of the model assumptions and retrieval values from air-borne sensors, and we have deployed these as part of the CoBOP and HYCODE field activities. Several of these (e.g. Bottom Classification and Albedo Package, BCAP, and Real-Time Ocean Bottom Optical Topographer, ROBOT) have been developed and tested on ROVs or AUVs (see below and Carder and Costello CoBOP report).

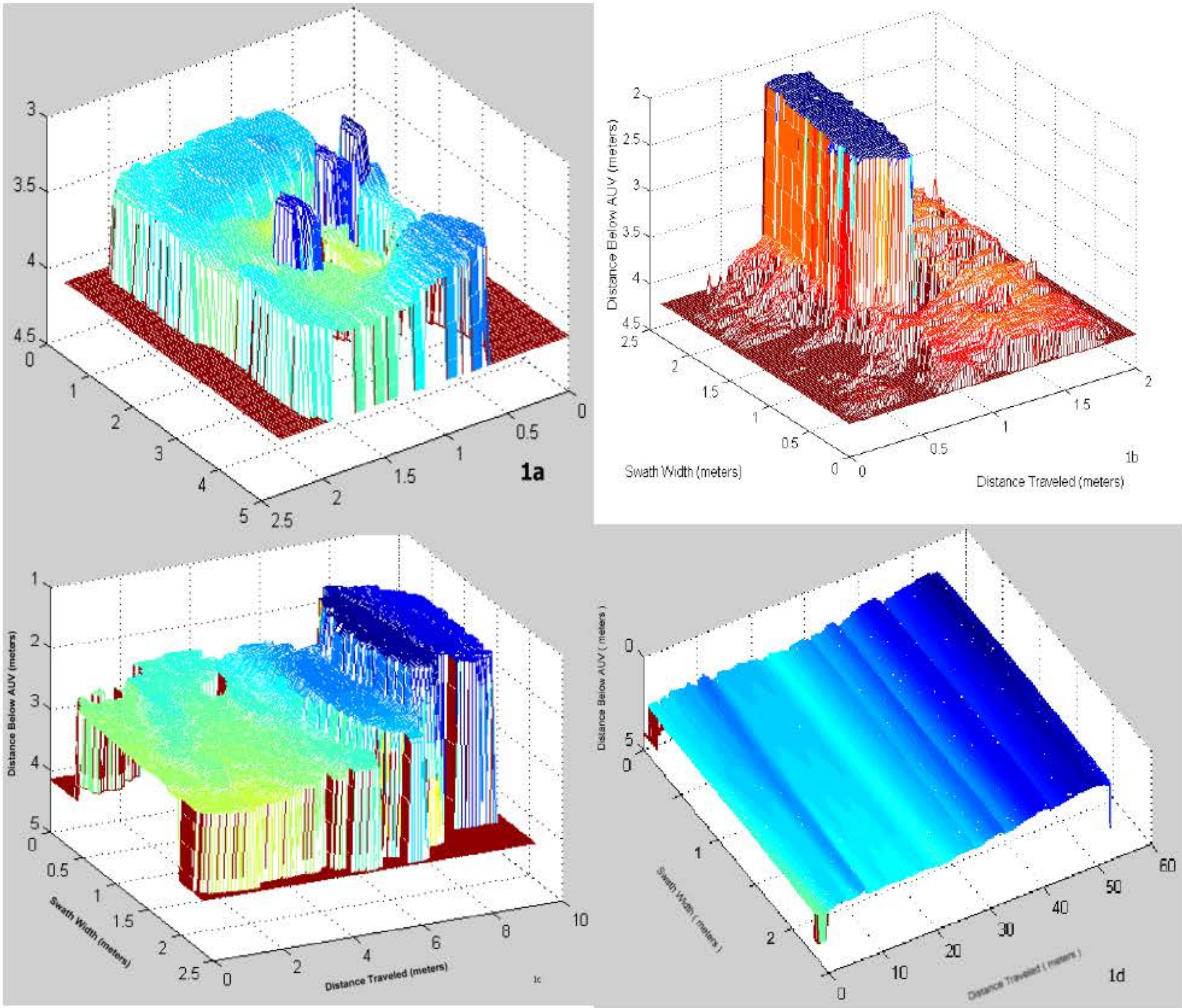
This project utilizes BCAP, a suite of optical instrumentation developed under previous ONR funding, to acquire the hyperspectral database required to deconvolve the components of the underwater and water-leaving light fields (Carder et al., 1998; Costello et al., 1997; English et al., 1998; Hou et al., 1998a; Patch et al., 1998). *In situ* instrumentation includes a 512-channel upwelling radiometer, a 512-channel downwelling irradiometer, two 6-channel, intensified bottom cameras, a single-channel, intensified bottom camera, a dual-laser, optical altimeter/chlorophyll probe, COTS instrumentation to measure attenuation, absorption, backscattering, and fluorescence at various wavelengths, and a real-time microtopography assembly. Two BCAP systems have been configured for deployment on both our ROSEBUD ROV and the Ocean Explorer class autonomous underwater vehicles.

As range-to-bottom or target is a critical parameter for optical models and varies markedly over coral reefs and rock fields, a bi-static micro-topography sensor, ROBOT, has been developed to provide range maps, micro-topography, albedo, and bottom texture (see Fig. 1). It is a surrogate for laser ranging devices that can fail to perform in turbid water. ROBOT has been designed as a payload module for deployment aboard the Ocean Explorer (OEX) class AUV developed by Florida Atlantic University. Prediction of system performance using remotely sensed data is being actively pursued.

WORK COMPLETED

- Solar-stimulated fluorescence imagery of the bottom, including natural and man-made objects, has been secured for depths from 6m to 30m at several sites using an intensified video camera and a narrow-band-pass (NBP) filter centered at 685 nm from both our ROV and the Ocean Voyager II AUV.
- Four major ROBOT missions were run during the past 16 months, two at Lee Stocking Island (Bahamas), one off Fort Lauderdale, and one off Sarasota. The first three were in clear waters (e.g. $c(532) < 0.4/m$) and successfully imaged sand waves, rocks, stromatolites, and walls (Fig. 1), and obtained at 3 knots micro-topography ($dz < 2$ cm) of 3m-wide swaths of the bottom from an Ocean Explorer AUV in bottom-following missions at 3m altitude. The fourth mission failed in the more turbid and less reflective environment off Sarasota, where waters with $c > 1.5/m$ are not uncommon. Since running the AUV closer to the bottom is not always an option, we performed tests of ROBOT in the flume under controlled conditions to establish the likely cause of the failure off Sarasota.
- We participated on several cruises last year, collecting Rrs, absorption, and pigment data on 1 NRL and 3 ECOHAB cruises so far, with the addition of slow-drop ROV BCAP measurements on 4 R/V Subchaser cruises, and full participation in CoBOP cruises using R/V Suncoaster and R/V Subchaser at Lee Stocking Island supporting slow-drop, AUV (ROBOT, BCAP, SIPPER), and ROV BCAP measurements of AOPs, IOPs, bottom albedo, and microtopography. These cruises accompanied many aircraft over-flights of AVIRIS and PHILLS as well as providing a variety of optical conditions to 200

km off the west Florida coast and to the clear waters of the Bahamas. Optical closure calculations involving k_d versus absorption and remote-sensing reflectance versus the Lee et al. (1998a, 1998b, 1999) model have been started.



1. 3-dimensional ROBOT imagery. Vertical axis is distance from AUV to bottom while horizontal axes show distance travelled along transects and swath width. 1a: Stromatolites arising out of sand bottom at Lee Stocking Island (LSI), Bahamas (29 May, 1999). 1b: Submerged wall in waters near Ft. Lauderdale, FL (Dec., 1998). 1c: Several hard-bottom ledges at LSI (22 May, 1999). 1d: sand waves on a shoal at LSI (21 May, 1999).

RESULTS

Due to the high attenuation of 685 nm radiation by water, essentially no solar radiation at that wavelength is reflected from below a few meters of depth (Costello et al., 1998a). However, the attenuation of the blue-green radiation band that pumps chlorophyll fluorescence at that wavelength is

lower by about a factor of twenty (Costello et al., 1998b). This has been exploited to produce high-contrast, NBP imagery of non-fluorescing objects silhouetted against the natural, solar stimulated (fluorescing) background for depths from 6 – 25m. The ability to acquire NBP imagery is, however, a function of the water IOPs within the excitation band. During an ROV deployment below 30m off Sombrero Key, for example, fluorescence from benthic diatoms was inadequate for the exploitation of this imaging method. However, in 25 m water depth in the Dry Tortugas and the Bahamas, there was bottom fluorescence sufficient to acquire imagery in the 685 nm band and even in a band centered at 730 nm. The parameterization of the method considering different bottom types and the spectral irradiance available at depth is underway.

A bi-static, laser-line-imaging system (ROBOT) has provided micro-topography of the bottom and of bottom objects with < 2 cm resolution in three dimensions at 3 knots. The targets imaged ranged from sand waves with a few centimeters relief to stromatolites (Adderly Channel, Bahamas) with more than one-meter relief. Laser power increase to 200 mW will permit 10 knot speeds and 5m ranges.

IMPACT/APPLICATIONS

Major progress in nowcasting the optical properties of the water column and bottom and albedo from remotely sensed data has been made this past year, including the Lee et al. (1998, 1999) publications inverting hyperspectral Rrs data for homogeneous water columns and the nowcasting of bathymetery and optical properties for the turbid waters of Tampa Bay. We recently published a neural network inversion scheme (Lee et al. 1998) which will be tested on a training set derived with the Lee optimization approach using a subset (0.5-1%) of scene points for the Tampa Bay imagery. Since optimization is accurate (D~8-10%) but slow (~5 seconds/pixel on an SGI O2), and neural networks are almost instantaneous (once trained) but less accurate (D~12-14%), this approach provides a practical method to deliver results in a rapid manner even for denied-access areas. Once a NN is trained for a given region it can be used rapidly as long as the optical parameters remain within the training range. Critical regions within the derived bathymetric scene can be evaluated as a test using the optimization approach and measured field data when available.

For AVIRIS, PHILLS, and COIS scenes over structured water columns (e.g. Tampa Bay plume, suspended sediment plumes, bubbles) a real-time approach is being implemented by instrumenting the ECOHAB buoys (see Weisberg report) with DURIP-funded optical sensors (see Carder DURIP report). Since these provide optical properties with depth and will be functioning during both clear and stormy weather, nowcasting retrievals from the buoy Rrs measurements above the ocean can be compared to measured depth, albedo and water-column optics to determine when and how algorithms fail. These data are critical to learning when to believe the retrievals and when not to, to learn how to improve the algorithms.

Solar-stimulated fluorescence imagery of the bottom can be acquired in any area where the depth is sufficient to effectively quench 685 nm reflected solar radiation and where blue-green radiation penetrates sufficiently to stimulate 685 nm fluorescence to a level which allows image formation by the sensor. A parameterization of the effective operational environmental variables including IOPs, AOPs, and bottom characteristics is underway (Hou et al., 1997, 1998b; Ivey et al., 1998; Lee et al., 1996a, 1996b, 1998a, 1998b, 1998c, 1998d, 1998e). The significance is two-fold: first, since the bottom is the source, the imagery acquired is free from the backscattered path radiance generally associated with contrast degradation in underwater imagery (Pratt et al,. 1997); second, animals and man-made objects do not, generally, fluoresce at 685 nm. Given the appropriate environmental

parameters, this makes possible the visualization of bottom objects which may not be apparent using either active or passive elastic reflective imaging techniques. Applicability ranges from assessment of the standing stock of sponges to underwater mine detection.

Real-time, high-resolution micro-topography also has diverse potential applications. The most obvious of these is to provide the range information required to correctly interpret actively or passively stimulated fluorescence imagery. Other applications include coral biomass quantification, sandwave analysis, and bottom type/structure/object classification. Real-time 3-D imaging will be achieved from AUV-deployed systems via RF-ethernet transmission via a surface-towed float or by direct, underwater, optical communication.

TRANSITIONS

A number of instrument systems and deployment platforms developed under this funding have transitioned from prototype engineering mode to operational scientific mode.

1. The BCAP package has been transitioned from the prototype Ocean Voyager II AUV to the OEX class AUVs and the ROSEBUD ROV, used operationally during CoBOP.
2. The R/V Subchaser is now routinely utilized for the deployment of underwater vehicles. Co-operative work has been performed with several ONR-funded efforts as well as with work funded through NRL-Stennis, NRL-Washington, and NASA.
3. The ROSEBUD ROV has transitioned from a test-bed platform to a working platform. During the 1998 and 1999 CoBOP field campaigns, for example, the vehicle was used to acquire 1,190 hyperspectral irradiance/radiance profiles and multi-spectral elastic and inelastic bottom imagery.
4. Several payload modules for the Ocean Explorer fleet of AUVs have been deployed and are approaching the stage where they will be available to support field operations. These include ROBOT and BCAP (described here) and three other payloads developed at USF: SIPPER and DLS (marine particle enumeration systems; see Hopkins report) and SEAS (a micronutrient and spectrophotometric pH sensor; see Byrne and Fanning reports).

RELATED PROJECTS

This project benefits from an association with the ONR project Coastal Benthic Optical Properties (CoBOP) and with FAU Ocean Engineering program. CoBOP field exercises allow the opportunity to deploy hardware systems developed under this funding to image bottom structure/objects while benefiting from significant ancillary data from other CoBOP investigators.

Similar symbioses exist with the ONR Bottom Boundary Layer project, the ONR HyCODE project, and with the multi-agency ECOHAB effort which have targeted the west Florida shelf as a study site (Weisberg, Walsh, Howd, Byrne, Fanning, Bissett). Our co-operative participation enhances these projects and makes complementary data available to us for our work.

Efforts within our group toward model inversion (funded through ONR/CoBOP/DURIP and NASA) utilizing remote sensing reflectance provides bathymetry and water optical properties.

Co-operative relationships are also foreseen with several other projects associated with the AUV and AUV sensor development program between USF and Florida Atlantic University. Our participation

(utilizing ROBOT) in Navy-sponsored mine detection exercises off Ft. Lauderdale in early December 1998 is just one example.

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